Hydrodynamics of the Nearshore

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LONG-TERM GOAL

The goal of this project is to predict the wave-induced nearshore circulation and the low frequency motions that exist near shorelines. Two aspects of this hydrodynamic system are of particular interest: rip currents on barred shorelines and the analysis of edge wave and shear wave motions.

OBJECTIVES

To determine the mechanisms for the generation of rip currents on a shoreline with sand bars and rip channels. To discover the reasons that rip currents are unstable in position and in time.

To develop a framework for analyzing the spatial and temporal structure of shear waves and other unstable wave-induced flows in the nearshore zone. To construct a dynamical model for the coupling and evolution of the spatial modes of the flow field, and to compare the low-order dynamical framework to a weakly nonlinear formulation based on three-wave coupling of shear wave and edge wave modes, as determined from linear theory.

APPROACH

For the rip current problem, laboratory measurements in a 20 m x 20m directional wave basin have been conducted. Wave height and horizontal velocities were measured over the whole basin. Mean flows and water level set-up was obtained by averaging the data.

To augment the laboratory data, a theoretical/numerical model for the flow instability of rip currents has been developed. The model examines the instability of the rip current by treating it as a jet, subjected to an increasing water depth. The instabilities are due to the shear in the jet, much as in a shear wave.

For the shear waves, the approach is to analyze numerically simulated flow fields (such as the unstable shear wave climates described by Ozkan-Haller and Kirby (1998) using principal component analysis (PCA), as described by Holmes *et al*. (1996). This leads to a possible description of a complex flow field in terms of a (hopefully) small number of dominant modes. Following Aubry *et al*. (1988), a nonlinear model coupling these modes can be constructed and hopefully will shed light on the mechanisms for the growth of large scale structures such as vortices in the nearshore circulation pattern. The aim is to also apply the method to spatially dense, measured flows in the field, such as those obtained using doppler radar techniques (Smith and Largier, 1995). Results of this approach will be compared to results obtained using a spectral, coupled-mode model for a combined field of weakly nonlinear edge and shear waves.

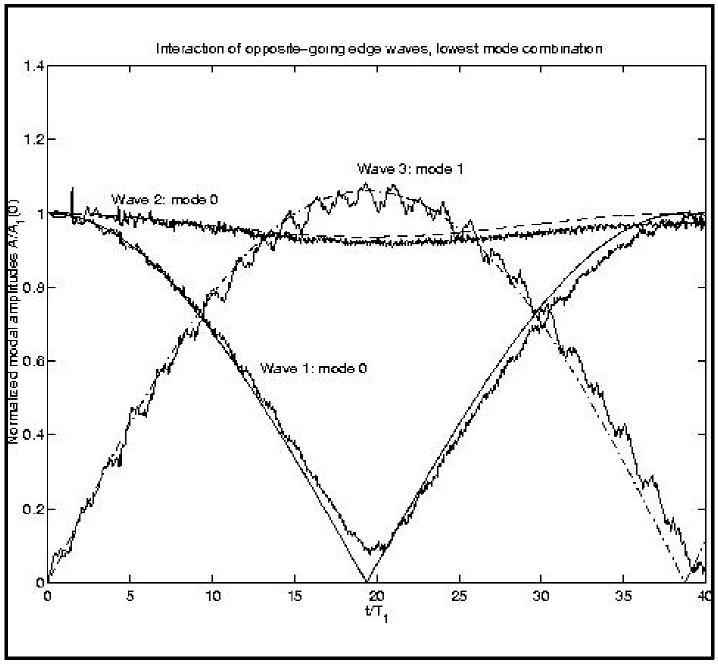
WORK COMPLETED

A series of experiments have been carried out in the Directional Wave Basin for waves over a sand bar with a rip channel. Figure 1 shows the directional basin with the 34 element wavemaker to the upper right and the sand bar system appears as the lighter areas at lower left; the beach is not shown (lower left). The rip current is moving towards the wavemakers through the rip channel, causing the waves to refract around the current and break on the current. Experiments have shown that the mean water levels induced between the sand bars and the beach by breaking waves provides a longshore hydrostatic gradient for longshore flows to the rip channels. The rip currents are unstable in time and space.

A numerical model has been written to predict the instability of these rip currents, based on previous works on the instability of plane jets. The rip current is modeled as a two-dimensional jet and the method of multiple scales is used to examine its linear (spatial) instabilities. The present model is based on the work of Nayfeh *et al.* (1974) and Saric and Nayfeh (1975), who applied the theory to boundary layer flows. The mean flow in the rip current flows the model of Joshi (1982), which was developed for tidal ebb flows from inlets. The fact that the depth under the rip current increases in the offshore direction has been included in the model.

At first order, the rip current instability model reduces to the Orr-Sommerfeld problem for parallel flows. At the next order, the effects of the transverse velocity component due to non-parallel mean flow and streamwise variations of the mean flow are included. The model predicts the streamwise variations of the disturbance amplitude, wavenumber, and spatial growth rate and these results are compared to the laboratory measurements. In addition, the influence of viscosity, non-parallelism, and depth variation in the longitudinal direction and the associated vortex stretching are examined.

A numerical model for calculating a combined field of edge and shear waves has been developed (Ozkan-Haller and Kirby, 1997) and has been applied to the study of a circulation field dominated by shear waves (Ozkan-Haller and Kirby, 1998). Development of the PCA techniques needed to analyse the resulting numerically-predicted flow fields is underway but incomplete at this time. The governing equations describing the mode-coupled, weakly nonlinear model for edge and shear waves have been developed (Kirby et al, 1998), and have been applied in a study of edge wave interactions on a planar beach.



Analytical (dashed lines) and Numerical (jagged lines) Results for Edge Wave Amplitudes in an Interacting Triad. Time is scaled by the edge wave period, T_1, of Wave 1.

RESULTS

The most important result from this study is the discovery in the laboratory that the rip current system is unstable. The fast seaward flowing jet oscillates laterally in the channel and pulsates in time.

Numerical modelling for rip current instability predicts the most unstable mode of this instability. This instability is similar to the shear wave instability of the longshore current, however, is it is an independent mechanism. It is likely in the field that both mechanism occur simultaneously.

The laboratory results also have been put in SHORECIRC to predict the presence of the rip current and the presence of the instability. Results agree well.

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IMPACT/APPLICATIONS

The main anticipated short-term impacts are a better understanding of the behavior of rip currents on a barred shoreline and an improved understanding of whether and how nonlinearities affect the balance of shear wave and edge wave energies on a given beach topography.

RELATED PROJECTS

The rip current laboratory data has also been used in FUNWAVE, a Boussinesq model developed with Army Research Office funding. By averaging output from this Boussinesq model, mean longshore and rip currents are obtained. Instantaneous vorticity calculations have been shown to be the same as the time-averaged vorticity. Finally the rip current data has been input to this model for comparison. A manuscript has been submitted to a journal on this topic.

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